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# CRYOGENIC MATERIALS DATA HANDBOOK

## YEARLY SUMMARY REPORT

SEPTEMBER 1963

AIR FORCE MATERIALS LABORATORY
RESEARCH AND TECHNOLOGY DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

PROJECT NO. 7381, TASK NO. 738103



(PREPARED UNDER CONTRACT NO. AF33(657)-9161
BY MARTIN COMPANY, DENVER, COLORADO
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## FOREWORD

The Materials Research Laboratory, Martin-Denver, prepared this report on work done between June 1962 and June 1963 for the data handbook on solid materials at low temperatures. The Air Force Materials Laboratory sponsored the work under United States Air Force Contract No. AF33(657)-9161, Project No. 7381, Materials Application, Task No. 738103, Data Collection and Correlation. The Air Force Materials Laboratory, Research and Technology Division, directed the work, with Mr. Marvin Knight as project engineer.

The personnel of the Liquid Hydrogen and Materials Laboratory, especially L. Hanzlick and D. D. Leightly, gave valuable assistance.

## ABSTRACT

The background, organization, and maintenance of the *Cryogenic Materials Data Handbook* are discussed. An experimental program and its accomplishments in the past year are described.

Handbook insert reports 12 and 13 were distributed in the past year. A new format for data presentation was introduced. Data included both original experimental results obtained under this contract and information from the literature.

# 1. INTRODUCTION

Selecting proper structural materials for booster and space vehicles using cryogenic propellant and fluid is a challenge because of the behavior of these materials at low temperatures. This behavior of a candidate material is usually determined by performing numerous tests to identify such mechanical properties as tensile and compressive strength, ductility, and modulus of elasticity.

To evaluate the mechanical properties of the many materials considered for cryogenic service would be a tremendous undertaking for any one investigator. Pooling information would greatly simplify this effort. This important function is accomplished in the Cryogenic Materials Data Handbook, which presents data generated by various investigators and forms the most complete compilation of cryogenic data available in this country today.

Personnel of the Cryogenic Engineering Laboratory, National Bureau of Standards, Boulder, Colorado, started this data handbook under the sponsorship of the Air Force Ballistic Missile Division. During the preparation of the handbook, its responsibility was transferred to the Aeronautical Systems Division. The 11th quarterly report, dated 15 February 1962, was the last addition to the handbook prepared by the National Bureau of Standards. Since that time the Materials Research Laboratory, Martin-Denver, has held the contract for the generation, assimilation, and presentation of data for the handbook.

The handbood must be continually reviewed and updated to maintain its high quality. When information on certain materials and properties is lacking, experimental data are generated under this contract or by other Research and Technology Division programs to satisfy the requirement.

The handbook user should be cautioned that the data do not represent design-allowable values. The data are merely typical, representing in many cases only limited test results. Because of the sensitivity of materials to small variations in chemistry and processing at cryogenic temperatures, these typical data should be used carefully, particularly when low safety factors are involved.

## 2. HANDBOOK ORGANIZATION AND MAINTENANCE

The handbook has been prepared in loose-leaf form so the data sheets can be easily removed and inserted. Original recipients of the handbook received 22-hole binders to accommodate the data graphs and text pages. Subscribers to the Office of Technical Services (OTS) reprints of the handbook progress reports and later additions to the contrac. distribution list receive three-hole punched sheets. The handbook will be standardized for three-hole punching in 1964.

The index system originally devised for the handbook allows the user to readily replace obsolete pages and add new information.

A three-part code is used to identify each data graph page. The first portion of the code is an upper-case letter identifying the material group (i.e., A = aluminum, B = colbalt, C = copper, D = iron, E = nickel, etc). The second portion of the code numerically identifies specific compositions [i.e., after E (nickel), 1 = Inconel, 2 = Inconel X, 3 = K-Monel, etc]. The third symbol in the code is a lower-case letter that indicates the property under consideration (i.e., a = yield strength, b = tensile strength, c = elongation).

Three symbols, therefore, identify a specific material and property. For example, E.C.3 indicates data for the effect of temperature on the elongation properties of a K-Monel nickel-based alloy. Modulus of elasticity data for 2014 aluminum alloy will be found on page A.8.f.

When a great deal of data are available for a specific property, supplementary sheets are identified by a digit following the property designation, such as:

A.8.b;

A.8.b-1;

A.8.b-2;

A.8.b-3.

A material and property index is submitted with each progress report.

To aid handbook users, an accumulative index has been prepared. The letters and numbers in the column at the left denote the material group and specific composition. The letters across the top of the page denote specific properties. The numbers in the boxes refer to the progress report in which the latest revision of the data graph(s) represented by the coordinates was issued. Each progress report includes a revised accumulative index.

Handbook inserts with a slightly different format have been prepared in the past year. The upper temperature limit of the graphs has been decreased from the original 500°F to 100°F, allowing more accurate and more legible curves. Other minor changes include the separation of unnotched, notched, and weld tension data and the inclusion of notch strength ratio.

Some of the handbook data have been replotted and assigned new reference numbers that reflect more readily available sources.

In certain cases, a great deal of information has been obtained for preparing a data graph. If overlapping or crossing of symbols for data in close agreement would make a graph illegible, a spread band is presented. This technique is restricted to cases with a significant amount of reliable data in close similarity. References are given for all data used in preparing the spread band.

Two insert reports, 12 and 13, have been prepared for the handbook and distributed in the past year. The former consists chiefly of tensile data obtained by General Dynamics/Astronautics and fatigue properties determined by Battelle Memorial Institute, both under the sponsorship of the Aeronautical Systems Division. References 1107 and 1109 designate these data. In plotting these data, additional information from Martin and NASA has been included. Progress report 13 consists chiefly of data generated by Martin under this contract. These data are identified by Ref 1115. Data from other sources have been included in plotting these results.

## 3. EXPERIMENTAL PROGRAM

The experimental program was designed to provide property information necessary to update the handbook. A variety of materials and properties have been selected. The following tabulation indicates the scope of the experimental effort.

| Cryogenic Materials Data Handbook Program | | | |
|---|---|---|---|
| Materials | | Properties | |
| Alloy Type | Designation | Test Type | Data Reported |
| Aluminum | 2014-T6 | Unnotched Tension | Ultimate Strength |
| | 2219-T6 | | Yield Strength |
| | 2219-T81 | | Elongation |
| | 2219-T87 | | Modulus of Elasticity |
| | 5456-H343 | | Stress-Strain Curve |
| | 6061-T6 | Notched Tension | Notched Strength |
| | 7039-T6 | | Notch Strength Ratio |
| Titanium | Ti-5Aℓ-2.5Sn | Weld Tension | Ultimate Strength |
| | Ti-6Aℓ-4V (Annealed) | Shear | Tensile Shear Strength |
| | Ti-6Aℓ-4V (Heat Treated) | Expansivity | Linear Expansion |
| | Ti-8Aℓ-1Mo-1V | | |
| Stainless Steel | A-286 | | |
| Nickel Base | Hastalloy B (20% CW) | | |
| | Inconel X | | |
| | D979 | | |
| Colbalt Base | L-605 | | |

The 7039-T6 aluminum alloy was recently included in the program as a substitute for 50%, cold-worked 304ELC stainless steel. The latter material was not commercially available unless a mill run was ordered.

These materials are evaluated at room temperature and three low temperatures, using the constant temperature baths as listed below:

| Temperature (°F) | Constant Temperature Bath |
|---|---|
| -110 | Dry Ice - Alcohol |
| -320 | Liquid Nitrogen |
| -423 | Liquid Hydrogen |

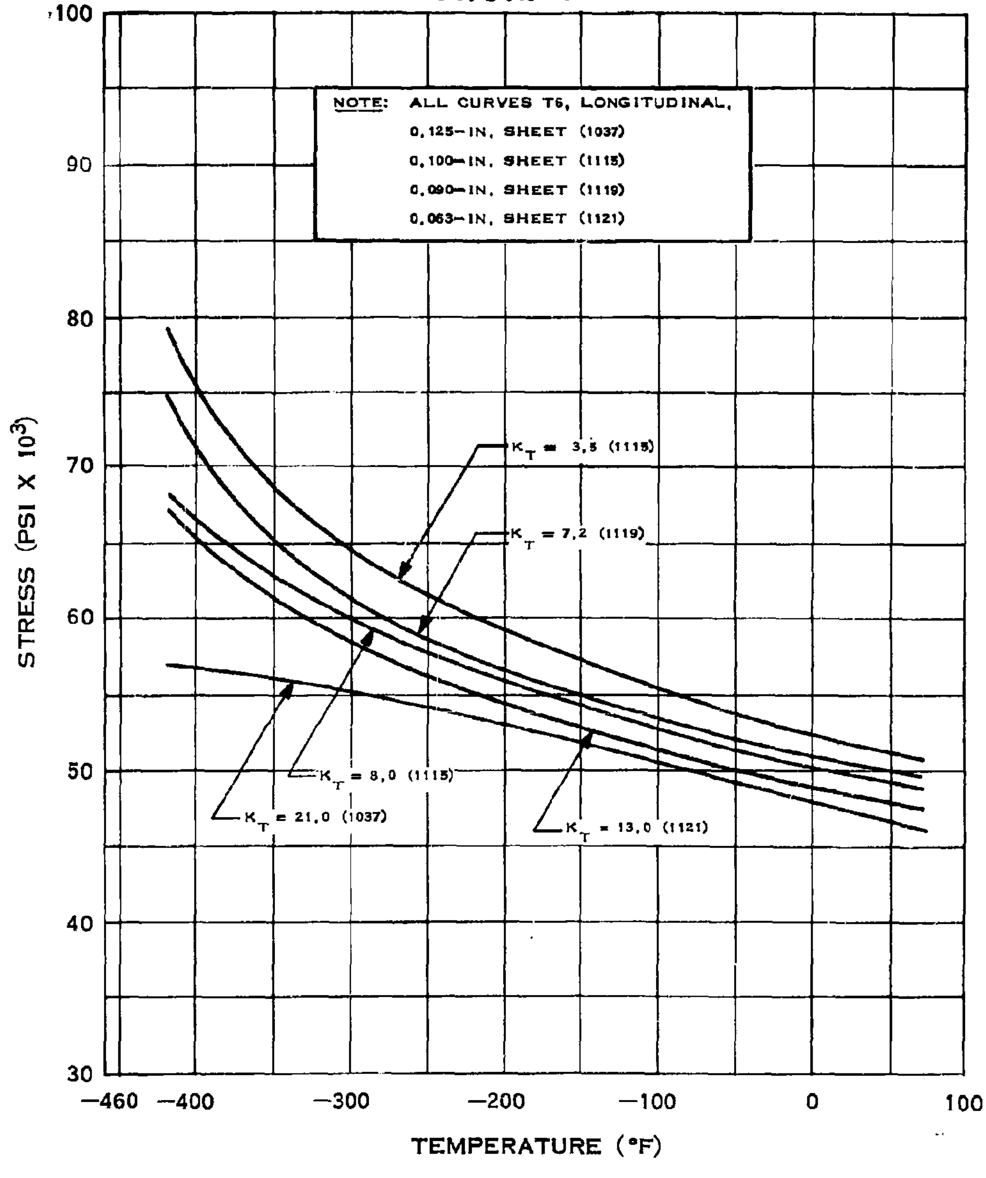
Six determinations are performed for unnotched tension and weld strength, triplicate determinations are used for other properties.

In the past year, tension properties for all materials except 7039-T6 were obtained. The 7039-T6 alloy has not been received.

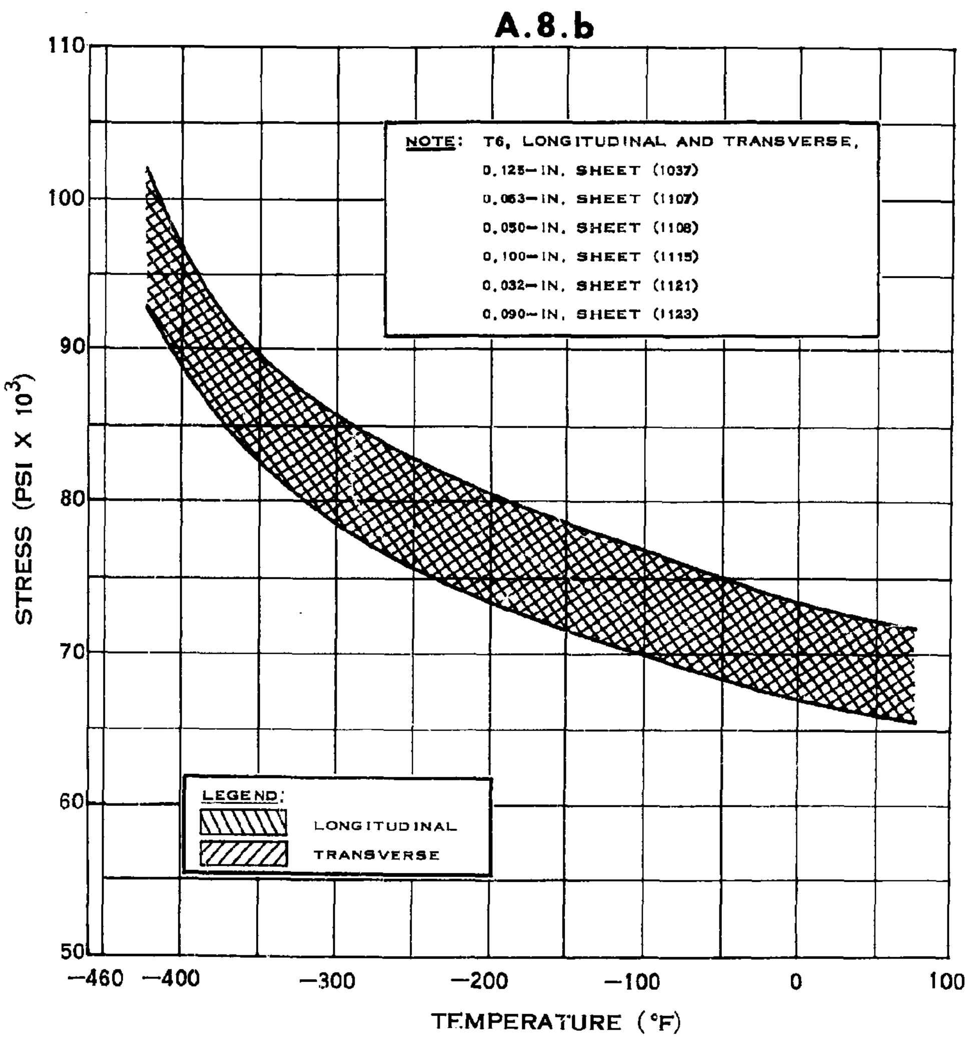
Shear properties have been obtained for some of the materials. Difficulties in preparing specimens of certain materials that exhibit sensitivity to cold working operations forced a change in specimen design. Thermal expansion tests are currently being performed, using a quartz tube dilatometer.

Typical examples of the new insert graphs are given in two accompanying figures. In the figure on Page A.6.b-1, data identified as Ref 1115 were generated by Martin under this contract. Data identified by Ref 1037, 1119, and 1121 were obtained from the literature. Note the excellent agreement of the multisource data. In the figure on Page A.8.b, sufficient data were available to prepare a spread band. It is hoped that acquisition of additional data will permit future presentation of average curves rather than spread bands

A.6.b-1




**NOTCH TENSILE STRENGTH OF 6061 ALUMINUM**




# TENSILE STRENGTH OF 2014 ALUMINUM

## 4. FUTURE PLANS

Plans for the second half of 1963 include additional experimental work and extensive revision of the handbook.

The few tests remaining from the first 12-month effort will be completed and new work started to:

1) Evaluate weld strength properties in aluminum plate;

2) Test fracture toughness;

3) Evaluate filament winding materials (tension, compression, flexure);

4) Impact test aluminum alloys.

The existing handbook will be completely revised and issued in early 1964 as a replacement for the existing document.

Examples of new data to be included follow:

1) Fatigue properties of aluminum and titanium alloys at cryogenic temperatures (NASA Contract NAS8-2631);

2) Mechanical properties of plastic laminates at cryogenic temperatures (AF Contract AF33(616)-8289);

3) Mechanical properties of pressure vessel materials at cryogenic temperatures (AF Contract AF33(616)-7719).

All graphs will be presented in the new format. Data for the 100°F to 500°F range will be deleted. More emphasis will be placed on the properties of structural nonmetallic materials.